

Powerflow calculations in powersystems considering traction load

V V Shestakova, I M Kats and A V Darkhanova

School of Energy & Power Engineering, Tomsk Polytechnic University, Tomsk, Russia

E-mail: shestakova@tpu.ru

Abstract. Nowadays, the negative impact of traction load on power system operation poses a serious problem that may lead to false tripping or even failures of relay protection devices and reduce the quality of electrical energy. This situation is typical for the Zabaikal power system, in which in some areas the share of electricity consumption by railway reaches 70% of total consumption. A computing tool, that would allow simultaneous analysis of the modes, both in the utility's grid and in the traction network, do not exist. The inability to carry out such analysis often leads to inconsistency in the actions of control centers and railway transport authorities, especially when maintenance planning. Mathematic modeling in such software systems as "Mustang", "RastrWin3", "MathCAD", "Matlab/Simulink", "PSCAD", "Kortes". The developed model represents Zabaikal power system and contain detailed railway between substation Razmahnino – Shilka, Chita – Mogocho. Negative-sequence voltage unbalance factors were calculated for the case of train movement between substation Razmahnino and substation Shilka. Also, the necessity of back-up relays tripping values correction is stated. It was shown that for the powerflow calculations taking into account the traction load, it is rational to use a complex mathematical model, which uses compatible software systems with the ability of quick and easy data exchange.

1. Introduction

Nowadays, a negative impact of traction load on utility grid operation is widely observed in numerous publications [1–6]. This effect is strongly pronounced when railway consume more than 50% of total demand in the powersystem.

This is typical for Zabaikal powersystem (ZPS), where separate railway sections consume up to 70% from total demand. Traffic flow is taking off from year to year and this fact deteriorates the current situation. According to [3] it is planned to increase freight traffic through Transib railway, hence, through Zabaikal railway too until 2030.

Badly coordinated actions both of the control centers and railway authorities may often lead to mistakes when network calculations accounting the railway influence. As a consequence, equipment failures, supply interruption both of traction and non-traction consumers.

For instance, in ZPS trains were de-energized because of 220 kV overhead transmission line maintenance works. Besides, false tripping of back-up relays is also possible.

2. Problem formulation

The challenge is there are no any means that would facilitate utility system mode analysis considering traction systems impact. As it was mentioned before, this fact causes inappropriate responses of control centers and railway authorities, especially while maintenance planning. The aim of this paper



is to develop a mathematic model, which is based on various software systems, to estimate mutual impact of supply and traction systems.

3. Traction systems power supply modeling principles

The main research method was mathematical modeling in such software systems as Mustang, RastrWin3, MathCAD, Matlab/Simulink, PSCAD, Kortex. Each one was used in accordance with their application area.

RastrWin3 has wide opportunities in powerflow calculations and steady-state modes optimization. Currently, this software is a major tool in all branches of System Operator of the United Power System. The RastrWin 3 database of the Zabaikal control area was a basis for our researchings. Should be noted that Zabakal power system is a “deadlock” as it operates apart from the Far-East power system.

Mustang was also main software for steady-state calculations and modeling electromechanical transients until recently. Now, it has been replaced by Eurostag, a more pioneering software package. Mustang has instruments to model automation components, for instance, automatic voltage regulation (AVR), automatic generation control (AGC) and so forth. Mustang as well as RastrWin3 (their databases are compatible) uses positive sequence schemes and this fact doesn't allow to determine electrical quantities in case of non-symmetric faults, besides, non-symmetric loads modelling is also impossible.

In Tomsk Polytechnic University Shemwizard, an add-on for Mustang, was developed. It automatically forms negative (NS) and zero sequence (ZS) schemes provided with positive sequence (PS) scheme. Shemwizard gave an opportunity to create the equivalent sequence network, which is based on the RastrWin 3 PS scheme. This is achieved by varying the impedance of the branch connecting PS and NS schemes in accordance with the Fortescue method. The total number of nodes and branches in the PS scheme is 238 and 277 respectively. The model contains generators with AVR and AGC, transformers, loads and 110–220 kV transmission lines, the Gusinozerskaya's power plant buses are taken as a swing node. A part of the 220 kV traction transit is showed on the Figure 1.

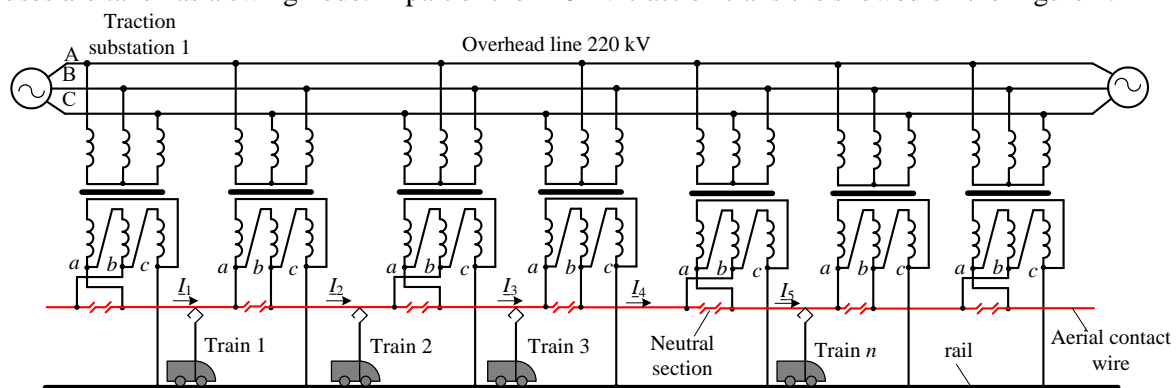


Figure 1. Connection scheme of traction substations to the longitudinal power supply line.

Mustang represents results as envelopes of complex PS and NS currents and voltages, which are time-varying. Such representation is not handy for evaluation, so by means of MathCAD an algorithm that returns instantaneous currents and voltage values for each phase was developed.

For more accurate modeling of 220 kV supply system between substation Darasun and Kholbon authors used Matlab/Simulink and PSCAD. This segment includes 4 traction substations. Initial voltage levels and generating power were based on steady-state mode parameters calculated by Mustang.

By means of "MatLab/Simulink" power circuits of a locomotive, including reversible converter and traction motors were created. Modeling were performed for three phases.

When performing powerflow calculations in MatLab/Simulink, it is possible to take into the account the type of traction motor. Mostly on Zabaikal railway trains travel that driven by pulse control DC motors. Recently, locomotives with asynchronous traction motors have appeared on tracks of Zabaikal railway.

Supply system of the Trans-Siberian railway uses the 1×25 kV scheme implemented by three-winding transformers. Interfacing is conventional - two phase wires to the catenary, third phase is grounded. To reduce the non-symmetric effects in traction systems phasing combinations of traction transformers along the trajectory of a railway system was provided.

In author's opinion, Matlab/Simulink and PSCAD are not suitable for modeling ZPS, which consists of several hundred nodes, as these software packages implement advanced mathematical apparatus, hence this fact would slow down large schemes calculation. In addition, it may be problematic to tune AVR and AGC systems.

Kortes, a specialized software system for railway research centres was used to determine the power consumed by non-symmetric traction load. Kortes supposed to estimate modes only for railway systems (27.5 kV), however, it allows to take into consideration plane and profile conditions, train working diagram and mass of trains. It's admitted that the mass of trains is between 4000 and 8000 tons. Modern locomotives travelling along Zabaikal railway consume from 2 to 10 MW depending on factors mentioned above.

Should be stated that primary power supply systems are represented in Kortes as infinite buses, where constant voltage level is sustained.

To sum up, created model allows to estimate currents and voltages in each branch and node in cases of both unbalanced short-circuit and non-symmetric loading conditions considering protective relaying and remedial action schemes operation.

4. Findings

In lines of the research, situations of simultaneous train moving were modelled. In such cases a substantial voltage decreasing takes place in utility grid. When trains work accordingly to the schedule and supply system operates normally, trains don't stop due to power outages. If several sections 220 kV supply system voltage are being repairing, it becomes below critical level (18 kV) and trains stop. On the other hand, voltage rises up to 110–130% of nominal voltage if there are no locomotives on the track. This also affects on equipment condition.

The next research area is verification of back-up relays set-point values. Calculations were performed considering electric values changing during electromechanical transient processes, still initial conditions for repeated switchings were taken into account. Experiments showed that it is necessary to calibrate thresholds of back-up transmission lines protection. In some emergency and restorative modes it is needed to adjust setting values in back-up relays of Kharanorskaya power plant main assets.

Below simulation results when connecting a train to the buses of traction substations are given. The train consumes about 3 MW. 35 kV buses of substation Karymskaya and 11 kV buses of substation Urulga were chosen for voltage monitoring. Asymmetry of currents were controlled on lines Darasun-Karymskaya and Darasun-Urulga. In the time ranges 0.04 – 0.12 s and 0.2 – 0.28 s the train receives power from substation Karymskaya and substation Razmahnino respectively, which causes an increase in currents of PS and the occurring of the currents of NS.

In the Figure 2a, positive and negative sequence currents I_1 , I_2 flowing through the Darasun-Karymskaya and theirs phase angles δ_1 , δ_2 calculated in "Mustang" are displayed. The phase currents oscillogram was obtained using RMS values and is presented on the Figure 2b. These calculation results coincide with the experimental data obtained in [4].

The authors tend to believe that using a probabilistic approach in modeling trains movement is preferable for powerflow calculations considering railway demand. The key difference between the calculations of traction networks from the calculations of networks with static loads is continuous change in train's location and consumed power (due to plane and profile conditions). For experiments

it was considered that average power of train is 3 MW and traffic interval is 25 minutes. Also, the number of trains located near the substation zone at the same time may vary. Hence, this fact causes fluctuations of voltage and current asymmetry levels.

The results are given in Figure 3. Calculations showed that increasing of the unit capacity and reducing of the traffic interval leads to decreasing of voltage levels and has slight influence on negative sequence voltage unbalance (NSVU) factor. According to the simulation results change in the train unit power by 5 times causes factor deviations by less than 1 %. Monte-Carlo method was used. It was shown to achieve confidence coefficient of 0.95 and accuracy of 0.1 it's needed to perform about 600 iterations.

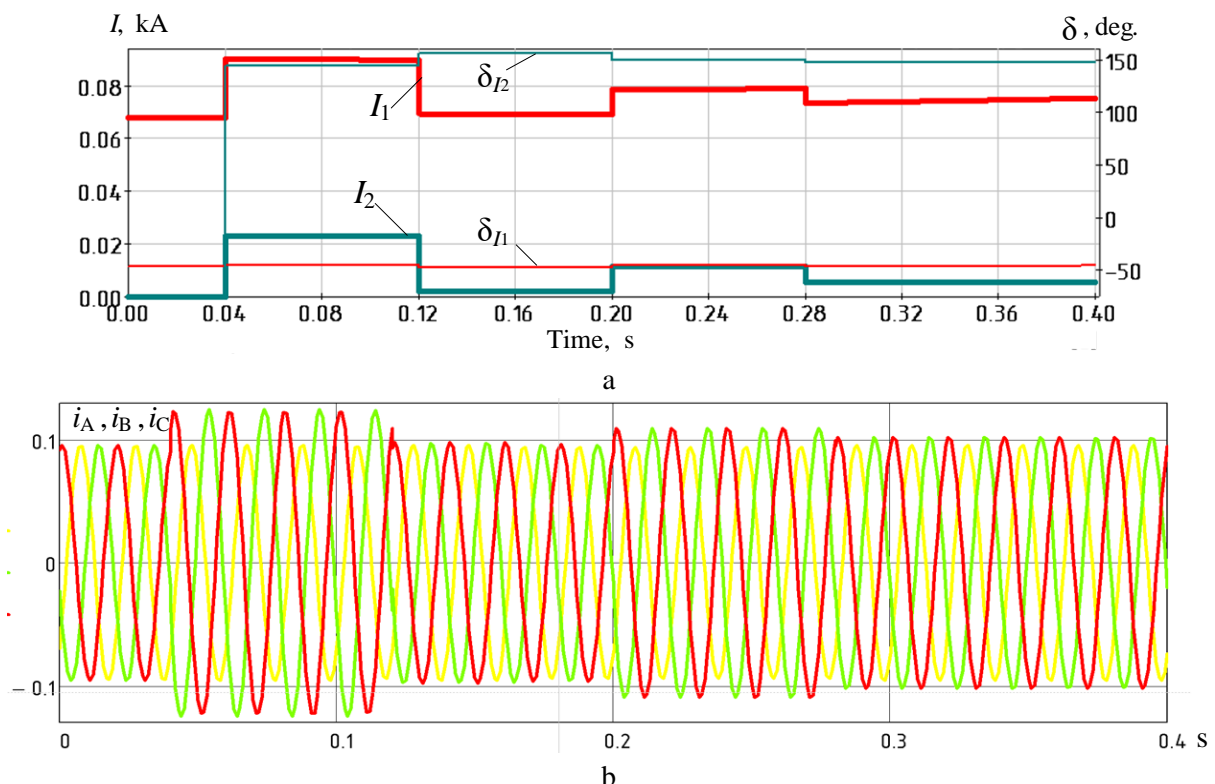


Figure 2. Connection scheme of traction substations to the longitudinal power supply line.

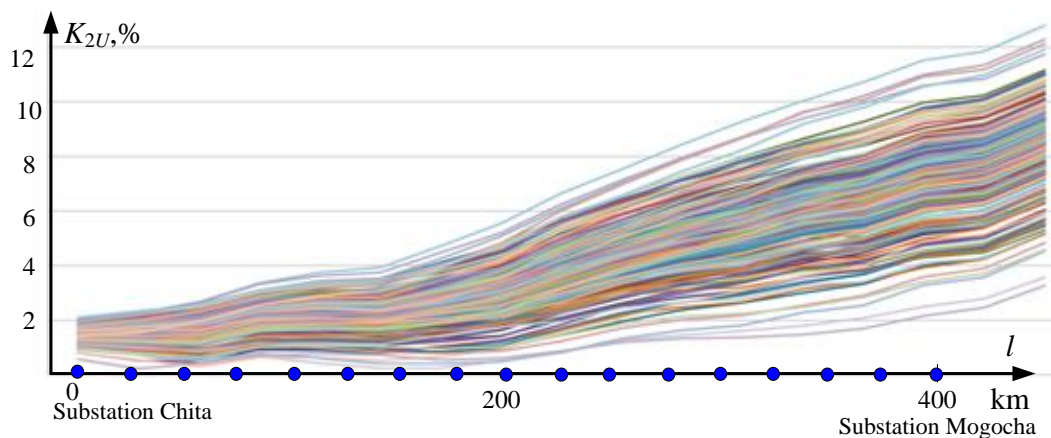


Figure 3. Change of negative voltage unbalance ratio (600 experiments).

As you can see the negative voltage unbalance ratio increases to the transit end. The value of the coefficient significantly exceeds the permissible level.

At present time, we are offered a range of balancing devices needed for current and voltage asymmetry compensation such as shunt compensation devices, series compensation devices, static var compensators (SVC), static synchronous compensator (STATCOM) and booster transformers [1–3].

According to [6] shunt compensation devices must be operated reliably and have rapid response of control systems. Series compensation devices possess positive regulation effect that obviously is a merit of such devices. However, series compensation condensers are vulnerable against ultraharmonics, which always take place in AC traction systems. SVC and STATCOM are devices of excellent performance due to relatively fast control systems, however tuning them properly may be a challenging process.

Installing booster transformer would be simpler and more reliable solution. It represents a three-phase transformer, which has its terminals connected in delta scheme to the catenary. Connection scheme of the booster transformer is shown on Figure 4.

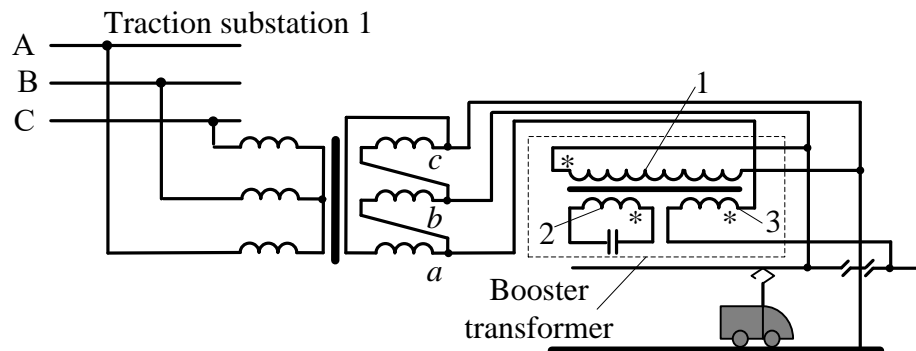


Figure 4. Connection scheme of the booster transformer: 1 – supply winding, 2 – compensating winding, 3 – auxiliary winding.

5. Conclusion

Complex mathematical model based on several software systems, that enable fast data exchange, is more advisable for powerflow calculations considering railway systems impact. It also obtains development dynamics of the processes in the integrated three phase - single phase electric scheme. This model may be applied for calculating parameters of booster transformer, relays set-point values correction and for maintenance planning.

References

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